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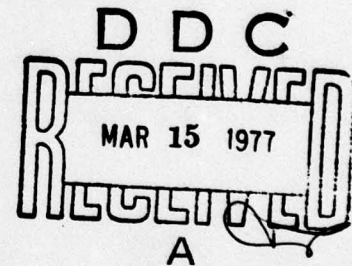
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STUDY OF UNDERWATER IRRADIANCE FLUCTUATIONS

[Shifrin, K. S., V. N. Pelevin, and A. I. Sud'bin, Issledovaniye fluktuatsiy podvodnoy obluchennosti, in: Optics of the Ocean and Atmosphere (Optika okeana i atmosfery), Institute of Oceanology of the USSR Academy of Sciences, "Nauka" Publishing House, Leningrad, 1972, pp. 174-181; Russian]

The study of the structure of the natural light field at different levels in the ocean is an important problem in oceanic optics. Data on the spectral, angular and polarization characteristics of the field are important both in themselves and as initial information for optical methods of ocean sounding. /174/

The simplest characteristic of the light field is the irradiance of the horizontal surface E . Observations show that the quantity $E(z)$ (z being the depth) undergoes considerable changes with time. Hence, in order to completely describe the natural irradiance in the ocean, it is necessary to know not only the mean values of E at different levels, but also its fluctuations.

The mean irradiance has been the subject of research for many years. In particular, it has been found to decrease with depth as $\exp(-\alpha z)$. Values of α (vertical attenuation index) have been obtained for various regions of the World Ocean. As for the study of irradiance fluctuations, data on this problem are very scarce.¹⁻⁵ They were all obtained in closed bays and pertain to small depths $z \leq 10$ m. We do not know of any measurements at large depths in the open ocean. The present paper describes a method of measuring underwater irradiance fluctuations in open regions of the ocean down to depths $z = 200$ to 300 m. The paper also presents some data from measurements of irradiance fluctuations made at four points of the Pacific Ocean at depths $z \leq 100$ m. These measurements were made during the fifth cruise of the ship DMITRIY MENDELEYEV in 1971. Values of the parameters characterizing the experimental conditions are listed in Table 1.

During the time necessary for performing one series of measurements, the height of the sun usually changed by 2 to 4° from the mean value given in Table 1. These changes had no significant effect on the nature of the fluctuations. No simultaneous instrumental recording of the waves was made, and this unquestionably restricts our possibilities of interpretation of the data obtained. /17/

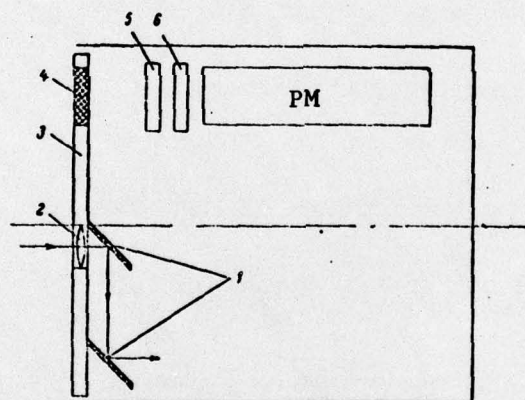
The measurements were performed with a composite detector of A. S. Suslyayev's design, which permitted the recording of irradiance and luminance. We initially proposed to make a simultaneous study of the fluctuations of both irradiance and luminance, and this instrument was therefore selected. However, the ship's yaw introduced large errors, which were difficult to take into account, into the readings of the luminance meter, so that we had to confine ourselves to the irradiance measurements. Studies of luminance fluctuations, which unquestionably are of great interest, should probably be made either from gyroscopic platforms or from stationary piers.

The optical design of the instrument is shown in Fig. 1. Light flux from milk-glass cosine collector 4 passes through a system of neutral 5 and colored 6 light filters and falls on a photomultiplier. The high, stabilized supply voltage of the PM is adjusted as a function of the light flux so that the working point of the PM

*Numbers in the right margin indicate pagination in the original text.

Table 1

Series No.	Number of station and date of measurements	Height of sun, deg	Depths, m	Wind speed, m/sec	Surface state points	α	State of atmosphere
I	367 4.03.71 Equatorial Cromwell current	70	2.5-20	3	1	0.053	2/1 Cu, Sc . ²
II	396 27.03.71 Central Pacific Ocean	80	2.5-30	6	3	0.041	4/4 Cu . ²
III	397 29.03.71 Transparent waters north of Rarotonga Is.	68	2.5-80	5.3	3	0.028	6/1 Cu, Cl . ²
IV	404 19.04.71 Equator. Western Pacific Ocean	80	5-100	5.4	3	0.053	4/4 Cu . ²



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Fig. 1. Optical diagram of irradiance and luminance meter. Explanations in text.

is at the center of the linear portion of the sensitivity curve. The set of neutral /17 filters 5 made it possible to change the light flux by five orders of magnitude. The photosensitive element used was an FEU-19M PM. The type of action was changed by rotating disk 3 through 180°, which made it possible by means of mirrors 1 to direct the radiation from the entrance illuminator of luminance meter 2 at the photodetector. During the measurements, the axis of the detector was always oriented vertically. All the results were obtained for the blue region of the spectrum. The spectral sensitivity curve of the detector is shown in Fig. 2.

The frequency range of changes in $E(z)$ was very wide: from thousandths to hundreds of hertz. Such a wide range is explained by the great variety of factors causing

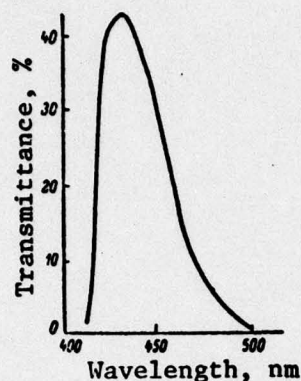


Fig. 2. Curve of spectral sensitivity of detector.

temporal changes in underwater irradiance values. Low-frequency fluctuations in $E(z)$ are caused primarily by the change in the height of the sun during the day, movement of clouds in the sky, and a slow change in the optical properties of the atmosphere and water by internal waves. Waves on the ocean surface and turbulent pulsations cause the high-frequency variability of $E(z)$.

Preliminary analysis of the experimental data obtained by V. N. Pelevin et al. during the 12th cruise of the research ship AKADEMIK VAVILOV in the Mediterranean and of the data given in Ref. 4 showed that the space and time inhomogeneity of the sea surface causes fluctuations of underwater irradiance in the frequency range from tenths to tens of hertz. The magnitude of these fluctuations surpasses by several orders of magnitude the fluctuations caused by such factors as turbulent or internal waves, and at large depths, the rms deviations of irradiance from mean values amount to fractions of one percent of $E(z)$. It was desirable, therefore, to separate the variable component from the total signal coming from the detector, so as to improve, in later processing, the accuracy and reliability of the spectral results obtained.

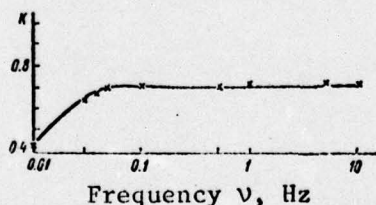


Fig. 3. Frequency characteristic of cathode repeater.

The variable component of the useful signal was separated by means of a cathode /17/ follower with a transmission coefficient of 0.72 in the relevant frequency range. The detected signal was then fed either to the loop of a K-115 oscillograph or to the input of a Minsk-22 computer through an analog-code converter.

Figure 3 shows the frequency characteristic of the cathode follower. As is clear from the graph, the signal passed through the system practically without distortions.

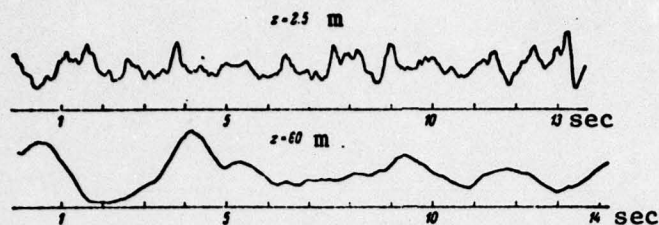


Fig. 4. Typical form of realizations of underwater irradiance fluctuations.

The anode supply of the 6N6 lamp was provided by dry B batteries, and the filament supply, by storage batteries, since otherwise, at large depths, 50-hertz stray pickups would highly distort the useful signal. An S1-16 oscillograph was used for visual monitoring of the variable signal fed to the computer input.

One realization was recorded for 3-6 min at a quantization frequency of 30-200 Hz, which enabled us to obtain a reliable spectrum from 0.2 to 30 Hz.⁶ A typical form of the realizations of underwater irradiance fluctuations at different levels is shown in Fig. 4.

RESULTS OF THE EXPERIMENT

Figure 5 shows the ratio obtained of the standard deviation of irradiance \sqrt{D} to the mean irradiance E as a function of depth. It is clear that \sqrt{D} decreases much faster than E . The same curves plotted on the log scale give the following approximate dependence:

$$\frac{\sqrt{D}}{E} \sim (z)^{-1.2}.$$

Unfortunately, we cannot quantitatively compare our data with those obtained by other authors,^{3,4} since the experimental conditions are very different. However, the general pattern of decrease in $\frac{\sqrt{D}}{E}$ as a function of z^{-1} is clearly visible in all cases.

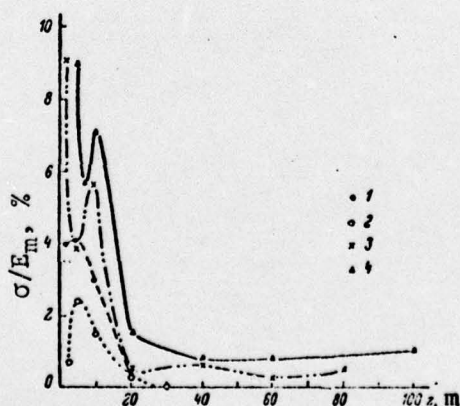


Fig. 5. Changes in the variation coefficient with depth.

1 - 4.03.7 st. 367; 2 - 27.03.71 st. 396; 3 - 29.03.71 st. 397; 4 - 19.14.71 st. 404.

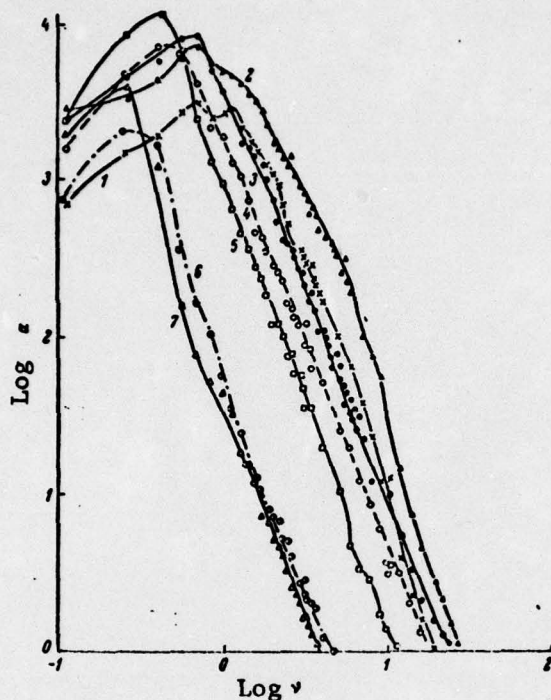


Fig. 6. Estimates of energy spectra.
Depth, m: 1 - 2.5, 2 - 5, 3 - 10, 4 - 20, 5 - 40, 6 - 60, 7 - 80.

Figure 6 shows estimates of energy spectra obtained by processing the realizations of stationary processes $E(z)$ for different z . These curves are the same in shape and character as those given in Ref. 4. Analysis shows that the spectral intensity decreases with frequency ν as ν^{-n} , where n changes from 2.5 to 3.5. The value of n is not given in the paper cited, but we were able to estimate it approximately at 2.8.

It is evident from Fig. 6 and Table 2 (st. 397) that with increasing submersion, the contribution of the high-frequency components to the total energy of the process rapidly decreases.

Table 2

Depth, m	2.5	5	10	20	40	60	80
Relative amount of energy concentrated to 1 Hz, %	44	46	71	80	90	97	99.7

With increasing depth, the spectral density maximum shifts toward lower frequencies. These phenomena are apparently due to an increased role of multiple scattering, which acts as a smoothing filter on the high frequencies.

/180

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